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United States
Department of
Agriculture

Forest
Service

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Management**

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SATELLITE IMAGERY VERSUS AERIAL PHOTOS FOR MAPPING HARDWOOD DEFOLIATION: A PRELIMINARY EVALUATION OF COST AND ACQUISITION FEASIBILITY

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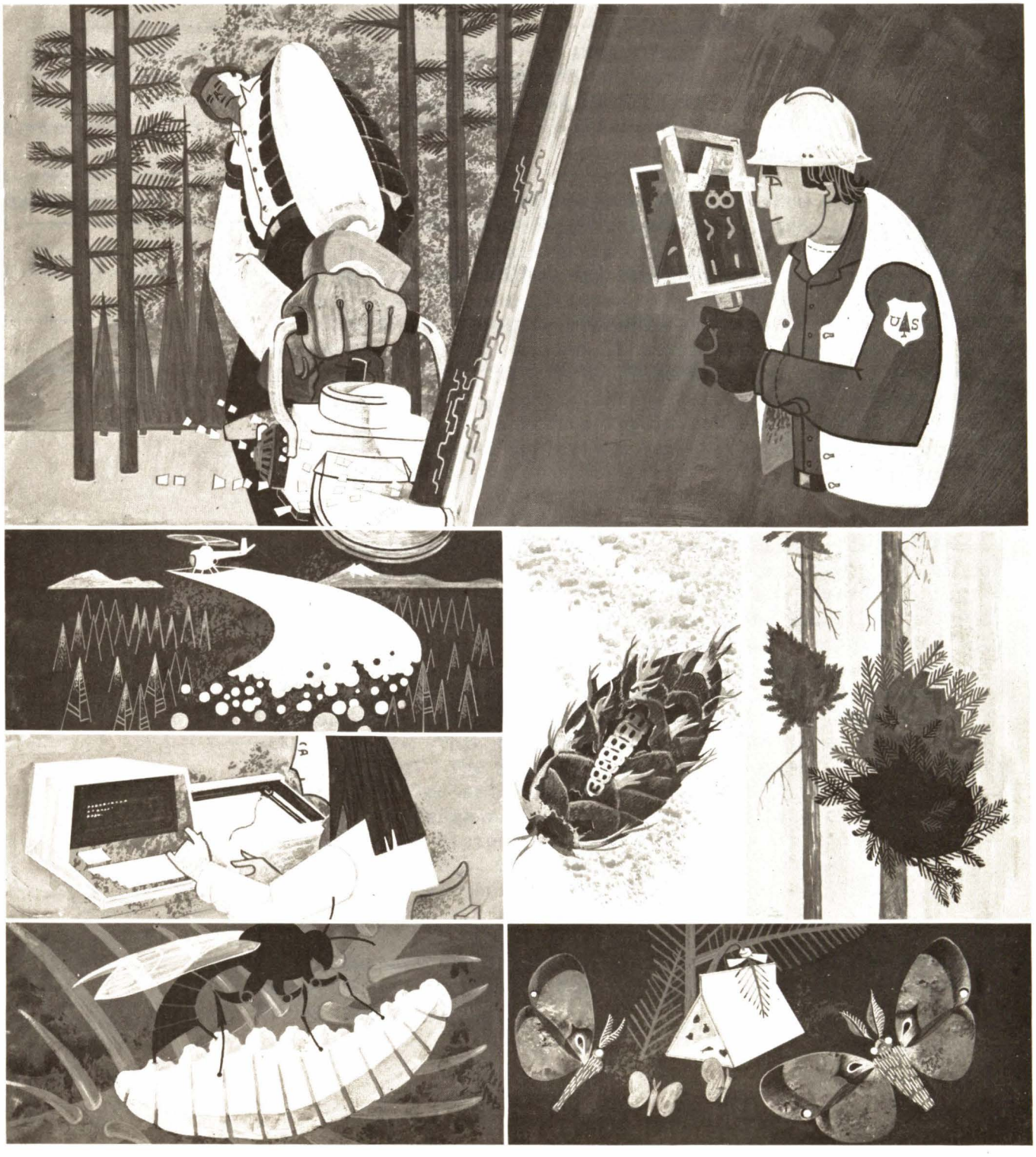

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Report No. 87-2

3400
May 1987

SATELLITE IMAGERY VERSUS AERIAL PHOTOS FOR MAPPING HARDWOOD DEFOLIATION: A PRELIMINARY EVALUATION OF COST AND ACQUISITION FEASIBILITY

By

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ABSTRACT

Use of LANDSAT TM or SPOT AVHR color composite products for mapping hardwood defoliation by the gypsy moth, Lymantria dispar, L., as alternatives to high altitude panoramic aerial photos is explored. Criteria used are acquisition costs and probability of data acquisition. Costs of both LANDSAT TM and SPOT AVHR color composite products are considerably below the cost of NASA U2-C, ER-2/IRIS II panoramic aerial photos (8.4 to 56 percent of U2-C, ER-2/IRIS II acquisition cost). However, the probability of suitable data acquisition is considerably lower with satellites because their orbital paths place them over the target area for only a few days during the designated acquisition window.

INTRODUCTION

Insect defoliation of hardwood forests, which is one of the most conspicuous types of forest damage, has the potential for being resolved and mapped from high altitude remote sensing platforms. Since 1983, defoliation of oaks and other hardwoods caused by gypsy moth, Lymantria dispar, L., in the mid-Atlantic states has been mapped from high altitude panoramic color infrared aerial photos taken from a NASA earth resources reconnaissance aircraft (nadir scale=1:32,500) (Ciesla and others 1984). This method has several advantages over aerial sketchmapping. The permanent record of damage on aerial photos permits detailed study for accurate location of defoliated areas and assessment of foliage protected by aerial application of chemical or microbial insecticides (Ciesla and Acciavatti 1982; Ciesla 1983). Acquisition cost of high altitude panoramic aerial photography ($0.80/km^2; $2.07/mi^2), while

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relatively low compared to the cost of conventional 1:24,000 scale 9X9-inch photography, is high when compared to the cost of aerial sketchmapping.

Satellite imagery offers another potential data source for mapping hardwood defoliation by gypsy moth and other hardwood defoliators, provided that this imagery is capable of accurately resolving damage. Studies by Dottavio and Williams (1983) in central Pennsylvania showed that LANDSAT multispectral scanner (MSS) imagery, with a pixel size of 80 meters, was capable of resolving areas of heavy gypsy moth defoliation. However, this imagery was only partially effective for resolving areas of moderate defoliation.

Recently two additional satellite sensors have been launched. both of which are capable of providing digital data with significantly higher resolution than LANDSAT MSS. These are the Thematic Mapper (TM), which accompanies the MSS on LANDSATs 4 and 5, and a pair of advanced very high resolution (AVHR) pushbroom scanners on board the French satellite SPOT. The availability of these sensors once again makes the question of mapping defoliation of hardwood forests from satellites intriguing. Purpose of this paper is to evaluate feasibility of acquiring color composite images, taken by LANDSAT TM or SPOT, as alternatives to high altitude panoramic aerial photos for mapping defoliation by gypsy moth in the Eastern United States.

DATA REQUIREMENTS

Survey Objectives and Products

The purpose of annual gypsy moth defoliation surveys is to determine the location and extent of infestations. Defoliation is usually classified into two intensity strata; moderate - 30 to 60 percent of the foliage removed, and heavy - greater than 60 percent of the foliage removed. Some states, however, only recognize a single defoliation class; aerially visible. Data are recorded on USGS 1:24,000 scale 7-1/2 minute series maps. Geographic information systems are beginning to be used for storage and analysis of these data (Dull and others 1986). Statewide and regional composite maps of defoliation are made from the base series. Tabular data on the area defoliated, by political subdivision or landownership class, are compiled. These data are used to monitor the status and trend of infestations, plan future suppression projects, or identify areas where extensive tree mortality may occur in the future.

Constraints

The primary constraint on data acquisition is the relatively short time period of peak defoliation. If data are acquired too early, not all of the feeding damage will have occurred and the total area of damage will be underestimated. If data are acquired too late, the current year's feeding will be partially masked by refoliation. In the mid-Atlantic states, gypsy moth larvae generally complete feeding by late June or early July. Peak defoliation is present until about mid-July after which refoliation begins.

This relatively narrow acquisition window is further complicated by the fact that periods of peak defoliation may vary within the area to be surveyed because of local weather and topographic conditions. Larval development is usually slower in the more northerly areas or at high elevations; consequently, defoliation may occur somewhat later on these forests.

The average period of peak defoliation by gypsy moth for the target area is estimated to occur as follows:

1. East of 77°50' longitude and south of the Maryland/ Pennsylvania state line - June 23 to July 5.

2. All areas west of 77°50' longitude and areas north of the Maryland/Pennsylvania state line which are east of 77°50' - July 1 to July 15.

These estimates are used to define the photo acquisition periods for high altitude panoramic aerial photography (Anonymous 1986).

Another constraint on data acquisition is the number of favorable days during which data can be acquired. According to tables published by Lee and Johnson (1985), there are an average of 2.64 days with less than 10 percent cloud cover in the target area during June and 2.2 days during July.

Defoliation maps and tabular data on areas defoliated must be available by early August for inclusion in status reports.

ALTERNATIVES TO DATA ACQUISITION

Three sensor capabilities, one operational and two yet unproven, were considered as alternatives to acquisition of data for mapping hardwood defoliation for this analysis. These are high altitude panoramic aerial photos, the LANDSAT Thematic Mapper (TM), and the SPOT AVHR (Table 1).

TABLE 1. COMPARISON OF ALTERNATIVE SENSORS FOR MAPPING DEFOLIATION BY GYPSY MOTH

Platform/ Sensor	Land Area Covered by a Single Scene (km^2)	Image Resolution
ER-2/IRIS II	140	0.33 meters
SPOT-1/AVHR	3,600	20.00 meters
LANDSAT/TM	31,450	30.00 meters

High Altitude Panoramic Aerial Photos

High altitude panoramic aerial photos, taken from a NASA U2-C or ER-2 Earth Resources Reconnaissance aircraft have been an operational technique for mapping defoliation caused by gypsy moth in several mid-Atlantic states since 1983 (Ciesla and others 1984; Anon 1985; Acciavatti and Ward 1987). Photos are taken with Kodak[2/] SO-131 High Definition color-IR transparency film during the specified acquisition window at a nadir scale of 1:32,500. An Itex IRIS II optical bar camera with a 90° field of view is used for photo acquisition. Each photo frame is 5-1/2 X 39-1/2 inches in dimension and covers a land area of approximately 140 km^2. These photos are of extremely high resolution; approximately 0.33 meters at nadir.

Defoliation is classified by monoscopic interpretation of the transparencies. Location of defoliated areas is transferred to a map base using a simple sketchmapping technique (Ward and others 1986).

LANDSAT Thematic Mapper (TM)

The LANDSAT satellities have been acquiring earth resource data since 1972. All have been in a polar orbit and return over the same point on the earth's surface every 16 days. The Thematic Mapper (TM) was first launched on LANDSAT 4 on July 16, 1982, and a second TM was launched on LANDSAT 5, March 1, 1984. Both satellites are still operating although the TM on LANDSAT 4 has been shut down due to technical problems. The TM records data in seven spectral bands including three visible, three near IR, and one thermal IR. A number of three band natural color or false color composite products can be made of a TM scene using various combinations of visible and IR bands. Land area covered by a single TM scene is 170 X 185 km or 31,450 km^2. Image resolution for the visible and near IR bands is 30 meters. This is considerably higher than the 80 meter resolution of the LANDSAT MSS. LANDSAT was recently transferred from the public to the private sector and is presently operated by Earth Observation Satellite (EOSAT) Company of Lanham, Maryland.

SPOT AVHR

The French satellite, SPOT-1, was launched on February 21, 1986. In a phased polar orbit 832 km above the earth's surface, the satellite overflys each of 369 ground tracks every 26 days. SPOT contains a pair of advanced very high resolution (AVHR) "pushbroom" scanners, each capable of sensing in either the panchromatic or multiband mode. In the multiband mode, data are recorded in two visible bands and one near IR band. This mode is of interest for mapping hardwood defoliation because color composite images resembling a color-IR aerial photo can be produced from the data. Image resolution for the multiband mode is 20 meters. Land area covered by a single SPOT scene is 60 X 60 km or 3,600 km^2. SPOT has an off-nadir

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2/ Mention of commercial names is for convenience only and does not imply endorsement by USDA Forest Service.

viewing capability and can view areas up to ± 27° of nadir in increments of 0.6°. This permits data acquisition along two parallel tracks during the same orbital path. In addition, this feature makes it possible to view a critical area on several consecutive days and by virtue of the different look angles, obtain stereo coverage.

METHODS

Feasibility of acquiring satellite data versus high altitude panoramic aerial photos was based on two criteria; a direct comparison of acquisition costs and the probability that the data would, in fact, be acquired. The latter criteria considers the probability of the sensor being over a predetermined target area during the designated acquisition window and the target area being free of clouds. This analysis was based on a series of assumptions developed from data about the various sensors under consideration including the probability of data acquisition, the products of that acquisition, and the relative ability of each product to resolve defoliation.

Target Area

For purposes of this analysis the target area was defined as the target area of the 1986 high altitude panoramic aerial photo mission. This included all of Delaware and Maryland, south central Pennsylvania, northern Virginia, and the Allegheny National Forest in northwestern Pennsylvania (Fig. 1). Total land area requiring coverage is 71,155.07 km^2 (27,473 mi^2) (Acciavatti and Ward 1987).

Satellite Products

The initial satellite product to be used for mapping defoliation by gypsy moth was assumed to be color composite photo products rather than computer compatible tapes. These would be interpreted visually using essentially the same technique as interpretation of high altitude panoramic aerial photos (Ward and others 1986). One LANDSAT TM color composite product and two SPOT color composite products were considered (Table 2). Six LANDSAT TM scenes from four orbital paths, and 35 SPOT scenes from five orbital paths, are required to provide 100 percent coverage of the defined target area (Tables 3 and 4).

Ability to Resolve Damage

This analysis is based on the assumption that both satellite sensors are equally capable of resolving the same two classes of defoliation as is high altitude panoramic aerial photography. Obviously this is an unproven hypothesis and is simply used to establish a basis for comparing costs and logistics of using satellite imagery as opposed to aerial photography.

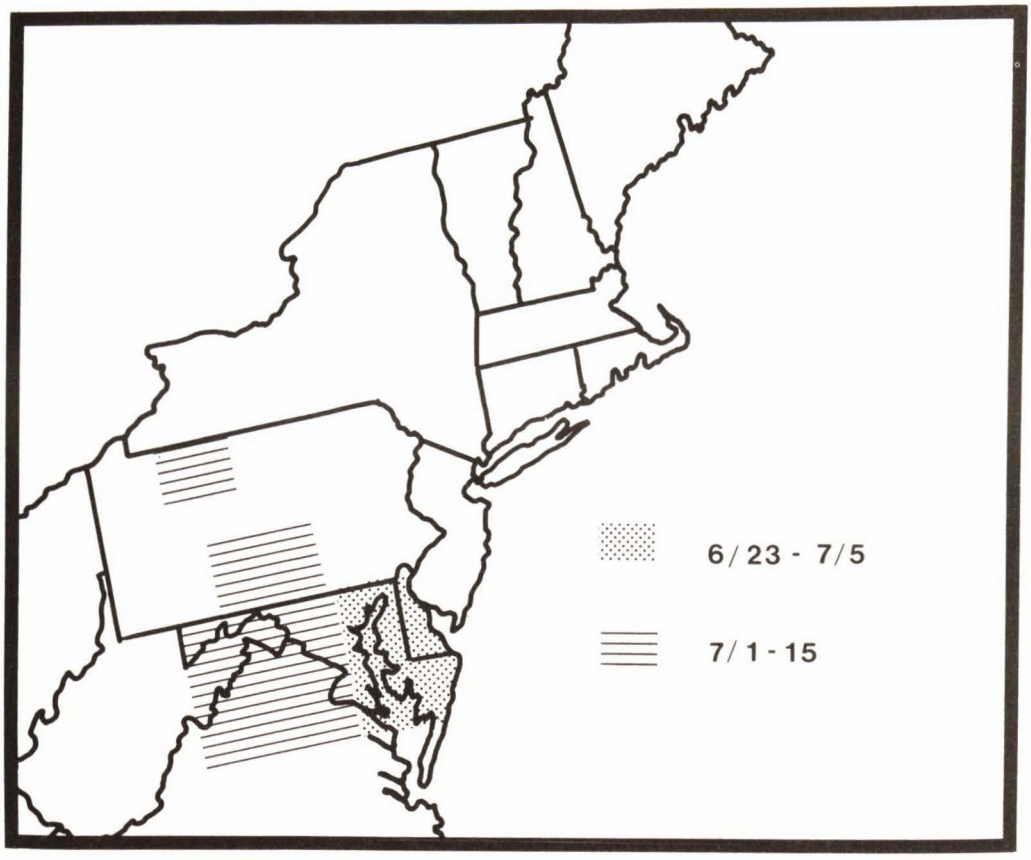

Figure 1. Area included in 1986 survey of hardwood defoliation by gypsy moth using high altitude panoramic photos (shaded area).

TABLE 2. SATELLITE COLOR COMPOSITE PHOTO PRODUCTS CONSIDERED AS POTENTIAL ALTERNATIVES TO HIGH ALTITUDE PANORAMIC AERIAL PHOTOS AND THEIR COSTS.

Satellite	Photo Product	Scale	Cost ($)
SPOT AVHR[1/]	Level 1B color composite print	1:250,000	410
	Level 1B color composite transparency	1:250,000	910
LANDSAT TM[2/]	Color composite print	1:250,000	800

1/ Data from February 1, 1986, price list, SPOT Image Corporation, Reston, Virginia.

2/ Data from May 1986 price list, EOSAT, Lanham, Maryland, includes cost of color composite generation ($300) plus cost of color composite print ($500).

TABLE 3. LANDSAT TM SCENES, DESIGNATED AS PATH AND ROW VALUES, REQUIRED TO PROVIDE 100 PERCENT COVERAGE OF THE GYPSY MOTH SURVEY AREA (n=6).

Row - (North/South)	Path - (East/West)			
	17	16	15	14
31	X			
32		X	X	
33		X	X	X

TABLE 4. SPOT-1 SCENES, DESIGNATED AS NOMINAL K AND J VALUES, REQUIRED TO PROVIDE 100 PERCENT COVERAGE OF THE GYPSY MOTH SURVEY AREA (n=35).

Nominal J Value (North/South)	Nominal K Value (East/West)									
	617	618	619	620	621	622	623	624	625	626
266	X									
267	X									
268										
269		X	X	X						
270		X	X	X		X	X	X		
271			X	X	X	X	X	X	X	X
272			X	X	X	X	X	X	X	X
273			X	X	X	X	X	X	X	X

Probability of Data Acquisition

Probability of acquiring suitable data (p^1) by a remote sensing system can be expressed as follows:

$$p = 1-p^1$$

where:

$$p^1 = \left[1- \frac{NCF}{N}\right]^d$$

and

NCF = number of expected favorable days during the acquisition period.

N = total days in acquisition period.

d = number of days sensor is available over the target area.

Variables used in the computations were as follows:

Expected Number of Favorable Days - Using data from Lee and Johnson (1985), the number of days with <10 percent cloud cover for Washington, D.C., the approximate center of the target area, was determined to 2.64 for June and 2.2 for July. Probability of a favorable day occurring was assumed to be uniform throughout each month. In addition, it was assumed that no serial correlation among days exists; that is, the probability of a favorable day does not depend on whether or not the previous day is cloud free.

Acquisition Window - Acquisition windows, as defined for the 1986 high altitude panoramic aerial photo mission, were used for this analysis (Anon 1986). These were June 23 - July 5 for Area 1 (south of Maryland/Pennsylvania line and east of longitude 77°50') and July 1-15 for Area 2 (north of Maryland/Pennsylvania line and west of longitude 77°50').

Sensor Availability - NASA aircraft, when deployed to Wallops Island, Virginia, for the gypsy moth mission, were considered to be dedicated to that mission. The aircraft are available for data acquisition each time a favorable day occurs except for one day during each acquisition window when down for repairs.

In 1987 LANDSAT 5 will be over the target area for two days during acquisition window 1, and three days during acquisition window 2. However the satellite will pass over each of the four paths required to capture the entire target area only once (Table 5).

For SPOT-1 a scenario was designed which maximizes SPOT-1's off-nadir viewing capability. This scenario provided for at least two scanning opportunities per orbital path during the designated acquisition window. SPOT-1 will be in an orbital path capable of acquiring data over the target area for five days during acquisition window 1, and eight days during acquisition window 2 (Table 6).

TABLE 5. PROJECTED DATES WHEN LANDSAT 5 WILL BE OVER THE GYPSY MOTH SURVEY AREA BETWEEN JUNE 23 AND JULY 15, 1987.

Acquisition Window	Path			
	17	16	15	14
1 - June 23-July 5	July 1	June 24 [1/]	July 3	June 26
2 - July 1-15	July 1	July 10	July 3	July 12 [2/]

[1/] Too early for Area 2 (July 1-15).
[2/] Too late for Area 1 (June 23-July 5).

TABLE 6. SCENARIO FOR SPOT-1 IMAGE ACQUISITION OVER THE GYPSY MOTH SURVEY AREA IN 1987.

Date	Revolution Number	Orbital path options for data acquisition (Nominal K values)		Number of Scenes
		Nadir	Off Nadir	
6/25	344		623,624	8
6/26	358	625,626		6
6/27	46		623,624	8
7/01	60	623,624		6
7/02	74		625,626	6
7/05	117		621,622	7
7/06	131		619,620	10
7/10	188		617,618	4
7/11	202	619,620		12
7/12	216		621,622	10
7/15	259		617,618	4

RESULTS

Cost Comparison

On a unit basis (per km^2) acquisition costs for both LANDSAT and SPOT color composite photos are considerably lower than for high altitude panoramic aerial photos. Since scene location for the satellites is fixed, coverage of a larger land area is necessary to ensure that all of the target area is fully covered. This increases the total project cost for satellite data which ranges from 8.4 to 56 percent of the cost of high altitude panoramic aerial photos (Table 7).

Probability of Data Acquisition

Computed probabilities indicate that the NASA ER-2 has the greatest chance of acquiring suitable data (Table 8). This is as expected since the NASA aircraft are on standby during the designated window and available for photo acquisition except when down for equipment repair. Both LANDSAT and SPOT have considerably lower chances of acquiring suitable data because their orbits place them over the target area only on certain days.

Examination of archived LANDSAT scenes acquired since 1983 over the target area confirm the low probability of data acquisition (Table 9). No more than three suitable scenes were acquired in any one year. Similar review of the SPOT data acquisitions to date indicate that multispectral data with less than 10 percent cloud cover was acquired on a single path (K=618) over the target area on June 26, 1986. Strictly speaking this acquisition was too early because it encompassed a portion of the target area which was west of longitude 77°50'. Peak defoliation generally does not occur in this area until July 1; consequently, in an "average" year estimates of defoliation derived from these scenes may be conservative.

By contrast, operational NASA U2-C or ER-2 panoramic photo missions flown in 1983, 1984, and 1986 were considerably more successful. In 1983 all of the designated target area was flown; however, portions of the western mountain regions were flown too early to resolve all of the defoliation (Ciesla and others 1984). In 1984 all of Delaware and portions of New Jersey, and Pennsylvania could not be flown because of unfavorable weather and only 70 percent of the target area was covered (Anon 1984). In 1986 virtually all of the target area was flown on July 4. Image quality was generally good although some scenes flown earlier contained noticeable haze or cirrus clouds.

DISCUSSION AND CONCLUSIONS

Both LANDSAT TM and SPOT AVHR data are potential cost effective alternatives to high altitude panoramic aerial photos for mapping hardwood defoliation caused by gypsy moth. In their present configuration the probability of either satellite acquiring suitable data is low. This probability could increase in the future, however, should additional earth orbiting resource satellites be launched or assuming that both systems are equally capable of resolving hardwood defoliation,

TABLE 7. COMPARISON OF ACQUISITION COSTS FOR PANORAMIC AERIAL PHOTOS VERSUS EARTH ORBITING SATELLITE COLOR COMPOSITE IMAGES FOR MAPPING DEFOLIATION OF HARDWOODS BY GYPSY MOTH.

Platform/ Sensor	Acquisition Cost/km^2 ($)	Approximate No. Scenes Required	Unit Cost of Scene ($)	Total Project Cost ($)	Project Cost as a % of ER-2/IRIS II Cost
U2-C, ER-2/ IRIS II	0.80	--	--	56,875[1/]	--
SPOT/AVHR (transparency)	0.25	35	910	31,850	56.0
(print)	0.114	35	410	14,350	25.2
LANDSAT/TM	0.025	6	800	4,800	8.4

[1/] Based on estimated costs, 1986 survey (Anon 1986).

TABLE 8. PROBABILITY OF SUITABLE DATA ACQUISITION WITH ALTERNATIVE SENSORS OVER THE 1986 GYPSY MOTH SURVEY AREA.

Platform/ Sensor	Acquisition Window: June 23 - July 5		July 1 - 15	
	Sensor Available Over Target Area (Days)	Possibility of Acquisition	Sensor Available Over Target Area (Days)	Probability of Acquisition
U2-C, ER-2 IRIS-II	12	0.637	14	0.643
SPOT-1/ AVHR	5	0.344	8	0.445
LANDSAT TM	2	0.155	3	0.198

TABLE 9. LANDSAT 4-5 SCENES ACQUIRED BETWEEN JUNE 23 AND JULY 15 WITH LESS THAN 10 PERCENT CLOUD COVER OVER 1986 GYPSY MOTH TARGET SITE 1983-86.

ROW	PATH			
	17	16	15	14
		-1986-		
31	X[1]	---	---	---
32	---[2]	July 7	X	---
33	---	July 7[3]	X	X
		-1985-		
31	June 25	---	---	---
32	---	X	July 13	---
33	---	X	July 13	X
		-1984-		
31	X	---	---	---
32	---	X	X	---
33	---	X	X	July 3[3]
		-1983-		
31	X	---	---	---
32	---	July 7	X	---
33	---	July 7	X	June 23 July 9

[1] X = all scenes have >10 percent cloud cover.

[2] --- = Scene not part of target area.

[3] Scene with 20 percent cloud cover.

the capabilities of both TM and SPOT are fully utilized for data acquisition.

It has not been established if either TM or SPOT color composite images are capable of reliably resolving hardwood defoliation. Because of their improved resolution over LANDSAT MSS, it is expected that they are at least capable of partially resolving moderate defoliation. An opportunity presently exists to test this hypothesis by interpreting selected LANDSAT TM and SPOT scenes taken over the target area in 1986 and comparing them to the results obtained by interpretation of 1986 high altitude panoramic aerial photos taken over the same area.

Both LANDSAT TM and SPOT AVHR have characteristics which might give either system an advantage over the other for this unique set of requirements. LANDSAT TM, with its capability for data acquisition in seven spectral bands, provides an opportunity to identify optimum band combinations for producing color composite images which might enhance defoliation over that which can be seen with a simulated color-IR image. SPOT, on the other hand, has an off nadir viewing capability which permits simultaneous data acquisition along parallel orbital paths. This increases the probability of capturing scenes for a higher proportion of the target area when suitable weather exists. Therefore, both satellites should be evaluated for their capability to resolve hardwood defoliation. This work is planned for the near future.

ACKNOWLEDGMENTS

Thanks are extended to Eric Byer and Eleanor Merideth, SPOT Image Corporation, Reston, Virginia, and Dr. Richard Kott, EOSAT Company, Lanham, Maryland, for providing information critical to the development of the scenarios described in this paper and for technical reviews. Ray Allison, Remote Sensing Coordinator, USDA Forest Service, Washington, D.C.; Dr. Robert Acciavatti, Northeastern Area, USDA Forest Service, Morgantown, West Virginia; and William Clerke, Southern Region, USDA Forest Service, Atlanta, Georgia, also provided technical reviews.

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